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TITLE: CLEAN AIR AND ENERGY: FROM CONFLICT TO RECONCILIATION

AUTHOR(S): Charles D. Kolstad, Economics Group (S-2)
William D. Schulze, Professor of Resource Economics,
University of Wyoming
Michael D. Williams, Air Quality Specialist. John Muir Institute

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Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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Abstract

Unconstrained energy resource development in the Rocky Mountain west is likely to threaten the environment and the health and well-being of the people. Impacts may be associated with visibility degradation, toxic concentrations of gases, and deposition of acidic or toxic substances. Because the possible benefits of energy development in the region are very large, there is great concern that constraints imposed by air quality regulation may preclude the use of important resources or make unduly expensive energy produced from the region. The conflict between energy and clean air in the region is exacerbated by non-energy sources, such as copper smelters and urban areas, that already pose significant environmental threats. The hard policy question is not how to preserve clean air resources or how to develop energy but how to achieve and balance both goals. This chapter quantifies the effects and regulatory costs and benefits of air pollution control and discusses policy directions to protect air quality while pursuing energy development.

Congress is currently reviewing the Clean Air Act of 1967 and its amendments of 1970 and 1977, the body of legislation protecting the nation's air quality. The act is vigorously attacked by some and strongly supported by others. Some criticism is leveled at governmental regulation in general: the contention is that regulation is becoming an excessive burden to society. Other criticism of the act maintains that some of our economic ills are due to an overly strict Clean Air Program. For example, some contend that energy development in the western US is being severely and unnecessarily hampered by provisions of the act that prevent the significant deterioration of air quality.

Opponents in the debate have valid points. High air quality is important in the western US; it should be protected. On the other hand, energy sustains the US economy; our nation is strained by the rapid price rises for energy over the past decade. Because of our reliance on imports, our economy is vulnerable to the whims of foreign oil suppppliers. If the western US can play a major role in ameliorating national energy difficulties, overly stringent air pollution regulations should not be permitted to impair energy development in the West.

The purpose of this chapter is to reconcile the apparent conflict between air quality protection and energy development in the West. After reviewing the nature of the western pollution problem, we discuss in turn the industrial costs of air quality protection and the monetary value of the damage to the environment by air pollution. Reconciling these costs and damages in a study of the Four Corners Region of the US, we conclude that high levels of energy development are consistent with the Clean Air Act and that industrial costs of current regulations are significant but modest relative to the value of the energy produced. If we consider a balance of costs and damages, current regulation appears to undercontrol sulfur dioxide (SO_2) emissions.

The Nature of the Western Pollution Problem

Environmental Impacts of Degraded Air Quality

There are basically three ways that air contaminants affect the environment. The first occurs with toxic concentrations damaging the health of plants or animals. The second relates to effects of altered light transmission through the atmosphere. The third concerns deposition of materials onto sensitive surfaces or deposition and subsequent transport into soils or aquatic ecosystems.

Toxic concentrations may result directly from emissions of pollutants such as carbon monoxide or indirectly as in the case of oxidants. Pollutants may be primarily local in character or they may occur over very large areas. Furthermore, the concentrations may display a steeply sloping frequency distribution curve or a very flat one. Energy sources tend to have different impacts associated with tall stacks as opposed to fugitive sources or secondary development.

Concentrations of the oxides of sulfur and nitrogen and fine particulate matter associated with tall stacks are apt to be very sensitive to terrain and produce relatively high ratios of maximum short-term average concentration to annual average concentrations. In the West the highest concentrations are likely to occur under stable conditions on terrain near effective stack height, that is, 300 to 500 meters above the stack base. The presence of intervening high terrain can greatly reduce concentrations. Relatively high concentrations may occur at distances of 30 to 50 km from the source if the terrain and meteorological conditions are appropriate. Frequently, areas receiving high concentrations are relatively unpopulated although some of these areas are in national parks where people may demand better air quality.

Fugitive or secondary sources tend to produce high, but relatively local, concentrations of particulate matter and possibly carbon monoxide and sulfur oxides. In these instances the concentrations display much lower ratios of the maximum short-term concentration to the annual average. These concentrations occur at the source height.

In most of the West, ambient concentrations of most pollutants are low compared to air quality concentrations permitted by standards designed to protect health and plant life. Exceptions are relatively widespread occurrences of moderate levels of ozone, occasional high levels of particulate matter, and local high concentrations of carbon monoxide associated with automobile traffic or fireplaces and woodburning stoves. Communities in valleys frequently experience periods of low ventilation that rival the infamous meteorological conditions of Los Angeles.

High levels of particulate matter may be associated with wind-blown dust, mining operations, dirt roads, or woodburning stoves and fireplaces. In most areas short-term air quality standards for particulate matter are exceeded occasionally.

Deposition of the oxides of sulfur and nitrogen and their transformation products may change the acidity of high mountain soils and waters or damage plant tissue. Local areas near sources may receive high levels of deposited materials, but major mountain ranges are also major receptors. The mountain ranges produce most of the run-off and thus gather pollutants through wet deposition. Furthermore, rugged terrain tends to enhance dry deposition, and the mountains have more vulnerable soils and vegetation.

Altered light transmission through the atmosphere can affect traffic safety, plant growth, or aesthetics. In the West effects on aesthetics are the best documented (1). The Southwest generally has the best visibility in the contiguous states although good visibility also occurs throughout the mountain West and in the western portions of the plains states. The southwest and mountain states also devote large areas to parks and wilderness.

There are principally two types of visibility effects: regional haze, in which distant features appear indistinct but the contaminants are not readily identified with any single source or complex of sources; and plume blight, a gray or brown smear across the landscape, with an identifiable, single source.

In the instance of regional haze the most important contaminants appear to be sulfates (1,2). On occasion, nitrates, wind-blown dust, or carbon-based aerosols may be important. In regional haze, aerosol concentrations usually vary only slowly within the mixed layer. Furthermore, principal contributors to regional haze may be hundreds of kilometers from the point of observation. For example, with a source emitting an annual average of one million metric tons of SO_2 in California, the sulfate concentrations ($\mu g/m^3$) would be 1.6, .52, .45, .20, and .17 in California, Arizona, Utah, Idaho, Montana, and Wyoming based on a model developed by Brookhaven National Laboratory (3).

Nitrates have the potential to play an increased role in visibility in the future. First, oxides of nitrogen (NO_x) emissions are expected to increase more rapidly than SO_2 or fine particulate emissions. Second, gaseous nitrates have very little effect on visibility but particulate nitrates can have significant effects. At low concentrations almost all nitrates are in the gaseous form, but at higher concentrations particulate nitrates form an increasing fraction of total nitrates. For this reason, there is a potential threshold for effects of nitrates on visibility.

Concentrations associated with visibility impacts during regional haze can be quite low. For example, the addition of about 0.3 $\mu g/m^3$ of sulfate could reduce visual range by about 30 kilometers (4) and studies (5) show that such change is significantly valued by residents. In comparison, the annual average standard for particulate matter is 60 $\mu g/m^3$ while the ambient standards for the precursor SO_2 is 80 $\mu g/m^3$. Thus, sources producing little impact in terms of toxic concentrations may yield large impacts on visibility.

Plume blight is a more local phenomena. During stable atmospheric conditions, pollutants confined in a shallow layer of the atmosphere, may be visible at distances on the order of 100 kilometers downwind. Either upwind high terrain or changes in stability can eliminate visual impacts. Primary particulate matter and nitrogen dioxide tend to be the most important pollutants in plume blight. Low level and fugitive sources tend to have very local impacts while emissions from tall stacks produce impacts at greater distances. Because the bulk of the pollutants is well above the ground, ground level concentrations in plume blight are usually very low and there is no relation between plume blight and ambient concentrations.

One other major group of sources influences air quality in the western regions. The copper smelters in Arizona, New Mexico, Utah, and Nevada have been associated with visibility impacts in the mountain West (1, 2, 4, 6). The smelters, large emitters of SO_2, have lower costs of control per unit of SO_2 removed than do power plants (7). Smelter emissions were approximately 2 million tons per year in the period from 1971 to 1974, but they have declined to about one million tons per year of SO_2 emissions.

Energy and the West

Air quality, a highly protected value in the western US, might be less important but for the extent of potential energy development planned for parts of the West. A very small area of the West covering parts of Colorado, Utah, and Wyoming contains essentially all of the high grade oil-shale resources of the US. Whereas forecasts vary, the Department of Energy anticipates shale oil production will meet the level of 200 000 to 700 000 barrels of oil per day (3). Other forecasts run into millions of barrels per day by the end of the century. Compare this to 1980 total US oil consumption of about 15 million barrels of oil per day (3). The oil-shale industry has the potential to grow very large and to place stress on air and other resources of the region.

Coal-based energy production has a large potential in the West. The western US contains over half of the nation's coal and over 90% of the nation's low-sulfur strippable coal (8). Western coal production is continuing to rise rapidly, particularly in the states of Wyoming and Montana. Aside from being shipped to the Midwest and East for combustion in power plants, coal can be converted at the mine to either electricity or synthetic gaseous or to liquid fuel for subsequent transport to population centers. The potential exists for large-scale coal conversion in the mountain west, particularly to serve the population centers of the Southwest and Pacific coast.

There are primarily three major new energy sources in the West. These are coal-fired power plants, coal syngas or synliquids, and oil-shale retorts with support facilities including mines, waste piles, and transportation networks for each. Although high concentrations of particulate matter may be found in the neighborhood of a mine, the mines have relatively local effects.

Coal-fired power plants emit primarily the oxides of sulfur and nitrogen and fine particulate matter. Control devices exist for both particulates and sulfur oxides, but oxides of nitrogen are controlled only by combustion techniques. In Japan, control devices for the oxides of nitrogen are being used for oil- and gas-fired installations, but techniques for coal-fired plants are less well developed. Consequently, a new, well-controlled plant will emit somewhat more oxides of nitrogen than sulfur dioxide.

Coal-fired power plants are relatively flexible in siting because coal and the needed water may be moved large distances to the plant site. In this context water is more expensive to transport than coal.

Coal synfuel plants also emit particulate matter, NO_x, and SO_2, but they tend to have relatively higher emission of hydrocarbons. For this reason they are likely to have more impact on ozone formation. However, for the same amount of coal processed, synfuel plants tend to have much lower emissions than coal-fired power plants. Emissions of NO_x from synfuel plants are much less likely to produce visible plumes because of the lower emission rates. Synfuel plants are also relatively flexible in their siting.

Oil-shale facilities tend to have emissions comparable to synfuel plants for the same energy input. However, oil-shale facilities have much less siting flexibility because of the large amounts of material they process.

Regulatory Background

Clean Air Act amendments of 1977 use a two-tiered approach for the protection of air quality in areas that are currently cleaner than ambient standards (9). If levels in excess of ambient standards occur in a region, non-attainment is reached, and provisions are activated to achieve the standards.

Of more concern to new sources in the West, are the provisions applying to areas with better air quality than the standards. In such areas the so-called Prevention of Significant Deterioration (PSD) provisions apply. Under the PSD provisions all new sources within major source categories may add specified amounts, PSD increments, to the concentrations of pollutants measured or estimated to exist in a baseline period. The increments are defined on the same basis as are the ambient standards, and thus for SO_2 there are 3-hour, 24-hour, and annual average increments. There are increments established only for total suspended particulate matter and sulfur oxides.

Increments are established for three different classes of area. Class I refers to national parks, national wilderness areas, and other areas for which the highest possible air quality is desired. Increments are only an intermediate step in determining construction of a new source. If the new source, in combination with other post-baseline sources, is expected to exceed permitted increments in some Class I area, the source may not be built unless the applicant demonstrates to the Federal land manager that there will be no adverse effect on air quality related values. If the source is projected to comply with the increments, the source may be constructed unless the Federal land manager demonstrates that there will be adverse effects on air quality related values.

Class II areas apply to most of the country where moderate industrial growth is desired. Currently this represents the entire country except for Class I areas. Class II increments must be met if a source is to be constructed. Class III increments apply to areas where large amounts of growth are desired and where air quality is a secondary consideration.

The PSD provision also requires that best available control technology (BACT) be used as determined on a case-by-case basis. However, in some jurisdictions BACT is assumed to be New Source Performance Standards plus whatever is required to meet increments.

The second tier of the approach restricts emissions independent of the location of the source. BACT is one such provision; New Source Performance Standards, which define the effectiveness of the control equipment that must be used, is another.

No specific provision sets a limit on SO_2 emissions although the increments and the BACT provisions reduce the rates of growth of this pollutant. The effects of the ambient provisions are further enhanced through requirements limiting the height of the stack used in estimating air quality.

One area of ambiguity in the regulatory process is fugitive dust. In the past fugitive dust was not considered in increment consumption determinations; however, after the policy changed, all emissions that can be reliably estimated are to be considered. This is potentially very important because the emissions associated with a dirt road are usually enough to exceed the Class II increments. Obviously, consideration of low level sources could pose a major barrier to development of all kinds.

Another difficulty in the regulation of particulates is non-attainment. Under the fugitive dust policy of the Environmental Protection Agency (EPA), occasional high concentrations of particulate matter are ignored unless there are industrial facilities or urban areas nearby. Thus, the construction of a new source is, in theory, sufficient to create a non-attainment area from an attainment area. In practice these considerations are usually ignored.

The Cost of Pollution Control

In this section we review the costs associated with air pollution control. We first consider the general options open to industry to reduce air pollution impacts. Second, we present results of an actual analysis for part of the West in which we show the total costs of reducing sulfur pollution.

Air Pollution Control Options

This section illustrates the variety of options open to industry to reduce pollution impacts. We wish to emphasize that pollution control is a continuous process in the sense that emission levels can almost always be reduced at some additional cost.

Most commonly, pollution control is thought of in terms of adding a "cleaner," such as a scrubber for a power plant, to the emission stream of a facility. However, other options are open. In fact, there appear to be four basic options open to industry to reduce air pollution: add-on pollution control, location shift to reduce impacts, process change, or reduced operations. If pressures on air resources in one area are particularly strong, then industry can move to another otherwise second-best location that permits more pollution. Industry can choose to change production processes to those inherently cleaner. A fourth "control" measure is exercised by consumers: as products become relatively more expensive, due to pollution control, consumers may shift their demand from such products towards less costly ones (that is, inherently cleaner to produce).

We now concentrate on these points in the context of electricity production, production of "synthetic" fuel from coal (liquid and gas), and oil-shale processing.

Add-On Pollution Control. One approach to control the deleterious effects of pollution is to add equipment for removing pollutants from the waste streams of a facility. The SO_2 scrubber, for example, is typically affixed to coal-fired electricity generation plants. To reduce emissions, a variety of equipment can be appended to production facilities currently in common use to reduce emissions. However, this may not be cheap. Figure 1 shows the approximate effects on electricity-generating costs from various levels of SO_2 control for coal-fired power plants. Pollution control costs can be quite moderate if control is relatively loose, or costs can be large if control is tight. Synthetic fuels facilities face similarly higher costs with more efficient treatment of waste gases.

Location Shift. Air pollution legislation in the US recognizes locational differences. In some areas, such as national parks, very little incremental pollution is tolerated; other areas can absorb large increases in pollution without violating ambient air quality regulations. When we read that air quality regulations have prevented construction of a power plant at a particular location, we often neglect to appreciate that at modest additional cost, the power plant site can usually be changed (and often is) to avoid violating air quality regulations (11).

In power production, additional costs from location shifts result from increased transmission distance for power and, when coal is involved, from increased shipment distance for that coal. Moving synthetic fuels facilities similarly results in increased costs associated with moving feedstock, whether coal or shale and, to a lesser extent, moving product an additional distance. The actual microscale location choice, of course, involves other factors such as water availability; nevertheless, these costs associated with additional transport are the major contributors to cost increases. Figure 2 shows some very approximate costs that might be incurred in moving an energy facility. For instance, a power plant could incur additional costs of as much as 1/3¢/kWh (10%) by being forced to relocate 100 miles from a prime location (12). On the other hand, this move could greatly reduce some of the air quality problems. Synthetic fuels plants similarly could be expected to incur additional costs from a location change.

Process Change. Production processes naturally evolve to conserve scarce resources and utilize abundant resources. This suggests that the most cost effective way to control pollution is probably not just to add control equipment to production processes that had their genesis when pollution was not a regulated problem. Rather, one would expect that, over a period of time, inherently clean processes will be developed, to lower the cost of emitting pollutants at low levels. The effects of process changes are seen clearly in the synfuels industry. A number of processes produce oil shale. Because of fundamental differences among the processes, each yields different emissions at different costs.

Unfortunately, data in this area is skimpy; however, one analysis (13) attempted to quantify the costs of pollution control of four different oil-shale processes. Data from this source on emissions of particulates and SO_2 are shown in Figure 3. Dramatic differences in emissions of these pollutants result from the four different processes. The TOSCO process produces less of both pollutants than does the Paraho process and thus might be preferred. (The Paraho process, however, produces less NO_x than does TOSCO). The Modified In Situ with Surface Retort and TOSCO are the preferred processes. When particulate matter is especially damaging, the former process is desired; and when SO_2 is most damaging, TOSCO is preferred. When air pollution policies throw up formidable obstacles to one production process, the efficient industry response may be to move away from that process towards a less polluting one.

As with the case of synfuels, there are process change options open to electric utilities. The simplest of these is switching to higher quality fuel (such as low ash/low sulfur coal) to reduce emissions. Because most coal in the West is already low sulfur, this option may have little use in the West. The potential for fuel switching in the East and Midwest, however, is significant. Other process changes include moving to other generation processes such as combined cycle/low Btu coal gasification or fluidized bed generation. These produce very low pollutant emissions at moderate increases in costs over current coal-fired steam generation.

Demand Shifts. An actual shift in consumer demand from products of polluting industries is unlikely to have an appreciable effect on energy production in the West. The small electric power price increases created by environmental control may dampen demand for electricity, but the effect is likely to be small. For synfuels, product prices currently are set by foreign oil. Unless synfuels production is only marginally economic and environmental controls tip the balance against synfuels, there will be essentially no price effects from additional control.

Regional Costs of Pollution Control

In the previous section we discussed the costs to individual facilities and the range of action open to industry and consumers to reduce pollutant emissions. In this section we are concerned with a region of the West with the potential for a variety of energy producers and pollution sources. In a region such as this, what are the overall costs of air pollution restrictions that allow industry to choose the best mix of strategies to reduce pollution at least cost?

We examine the Four Corners region of the Southwest. The region contains a large number of national parks and wilderness areas, those locales most highly protected by the Clean Air Act (Fig. 4a). The region also contains most of the nation's high-grade oil shale resources and significant amounts of coal for energy consumers in the Southwest and California (Fig. 4b). It is unlikely that there is any place in the US with more of a potential conflict between the goals of air quality protection and energy development.

Our approach to analyzing the costs of air pollution control in this region has been to develop a model of industrial response to air pollution regulation (14, 15). This Four Corners Model allows us to determine the total costs to industry of meeting a particular air pollution regulation, given assumptions about energy demand. For our purposes here, we will postulate three levels of energy demand for the year 1995--low, medium, and high--and then look at the average cost of supplying that energy. The total cost of meeting a particular regulation will be the difference in total cost under regulation vs without air quality regulation. Table 1 illustrates the level of demand assumed under the three scenarios. We assume that the hypothesized regulations apply to the 1987 to 1995 period.

Table 1. Four Corners region potential energy supply

	Low		Medium		High	
	1995	1987-1995	1995	1987-1995	1995	1987-1995
Electricity (10^9 kWh/yr)	82	15	140	58	177	62
Coal Synthetics (10^{12} Btu/yr)			350	350	1600	1300
Oil shale/Tar sands (10^{12} Btu/yr)			930	860	2100	1800
Total Value[a] ($\$10^9$/yr)	2.5	.44	11	8	25	13

[a]Based on 3¢/kWh electricity, $\$5.25/10^6$ Btu synfuels

Now let us consider the extra cost associated with controlling emissions of SO_2, one of the most significant pollutants in the study region. As we have seen, aggregate SO_2 emissions are closely correlated with regional visibility impairment. Without additional pollution controls (16), an average over the three scenarios of nearly 1.7 million tons of SO_2 is projected to be emitted annually in 1995 in the study region. What is the least cost way of reducing overall SO_2 emissions in the study region? The right-hand axis in Fig. 5 shows the total additional cost associated with reducing overall emissions. Costs presented in the figure represent an average over the three scenarios. For perspective, note that in Table 1 the average value of the energy produced from facilities coming on line in the 1987 to 1995 period is about \$13 billion (17). A very significant reduction in SO_2 emissions could be achieved before control costs amount to even a few percent of the total value of the energy produced. A caveat must be made that Fig. 5 presents the least-cost way of achieving the given aggregate emission levels. Improperly designed regulations may not result in the moderate costs presented in the figure.

A discussion of the costs of pollution control would not be complete without a discussion of the costs of current Clean Air Act regulations. In our discussion above, we were concerned with the cost of reducing the overall level of SO_2 emissions. Current regulations are concerned with a much more complex set of air quality goals. Nevertheless, we can use the Four Corners Model to simulate the costs of current PSD regulations. Our analyses show that, averaged over the three scenarios, the extra cost of current regulations is about $410 million annually. This translates to a cost of just under 4% of the value of the energy produced from the facilities coming on line from 1987 to 1995. Certainly the cost is significant (nearly half a billion dollars a year). How acceptable the cost is to society must be answered by society as a whole.

The SO_2 emissions from current regulations should be about 270 kilotons of SO_2 per year in 1995. As can be seen from Fig. 5, such an aggregate level of emission could be achieved at about half the cost. This however, is an unfair comparison. Current regulations protect local as well as regional air quality. A cap on regional emissions of approximately 120 kilotons of SO_2 in 1995 would provide the same level of local air quality (and significantly better regional air quality) as current regulations at slightly higher cost. Whereas it is probably possible to change current regulations to provide the same level of air quality protection at lower cost, current regulations do not appear to be dramatically inefficient, given the act's definition of air quality.

Does the act actually prevent any sources from locating in the study region? Our analysis, including considerations of visibility effects, suggests that this does not occur although siting is prevented in the vicinity of national parks and wilderness areas.

Are there other, non-energy, pollution sources, which may be cheaper to control than energy sources? Copper smelters contribute significantly to overall SO_2 loadings on the region and thus are major contributors to regional, as opposed to local, pollution. Smelters have relatively large SO_2 emissions that could be abated at costs somewhat lower than those of power plants. Existing smelters have SO_2 control efficiencies ranging from near zero to 90% or more. Some of the facilities with less effective controls could be modified at relatively low cost per pound of sulfur emitted. For example, one smelter has virtually no control on it at present, and 70% control would eliminate about 280 000 tons/yr of SO_2 emissions at an average cost of $11.6/ton. At 97% control, an additional 130 000 tons/yr of SO_2 emissions would be eliminated at an increment of $84/ton. Smelters with some control could be upgraded at a somewhat higher cost. One facility, for example, could upgrade controls from 65% to 92% and eliminate 130 000 tons/yr of emissions at a cost of $132 per ton of SO_2. Compare these costs to the marginal cost of SO_2 control from Fig. 5. The figure indicates that projected 1985 emissions under current regulations (270 kilotons per year) imply a marginal SO_2 control cost of approximately $800/ton. Thus, smelter control is a more cost effective way of reducing SO_2 loadings than strict control of energy facilities.

The Benefits of Air Pollution Control

The benefits of air pollution control for energy related industrial facilities in the Four Corners states and the Rocky Mountains are very different from those in the eastern US. The principal economic justification for air pollution control efforts to date has been health effects. For example, Lave and Seskin (18) have calculated that the urban health benefits of SO_2 control exceed the costs of control. However, in the West, energy related industrial facilities are typically located in sparsely populated rural areas where pollutant emissions into the air are unlikely to affect significant populations.

Health benefits are typically calculated using the following formula: (Value of Safety in Dollars) x (Reduced Risk from Pollution Control) x (Population at Risk).

Obviously, if the dollar value of safety and the magnitude of reduced health risks are controversial or questioned, if the population at risk is negligible, health benefits of air pollution control will be negligible. Thus, for rural industrial facilities in the West, we are forced to dismiss health benefits of air pollution control as insignificant.

This, however, is not to say that other sources of benefits may not be extremely large. In fact, evidence is accumulating that the aesthetic effects of air pollution, in particular visibility, may be equally as important as health effects on a national scale. We briefly summarize four available studies of the benefits of preventing visibility degradation. Note that, in sum, the studies suggest that pristine visibility in the national parklands of the West may be worth more to the nation as a whole than any other single source of air pollution control benefits yet identified.

Study 1: Visibility in the Four Corners Region

The Four Corners study (19, 20) represented the first empirical attempt to value enviromental effects on energy development in the West. The roots of the effort are in Davis (21) and Bohm (22). The study investigated the impacts of Navajo coal strip mine and the Four Corners electric generating plants in the southwest region. Aesthetic benefits of abatement of environmental damage resulting from air pollution (visibility), power lines, and land disturbance from mining activities were estimated. To prevent these effects individuals were willing to pay more than $80 per year (see Table 2). No bias tests (that is, hypothetical, information, instrument, interviewer, or non-respondent sampling) were formally reported.

Study 2: Visibility and Aesthetics at Lake Powell

Lake Powell, with annual visitation now approaching two million visitor days, is an excellent example of the tradeoff between preservation and development. The lake, formed by the filling of the Glen Canyon, retains the steep cliffs, rugged terrain features, and scenic vistas one associates with the Grand Canyon. Lake Powell is now accessible to pleasure boaters and others. Construction of the Navajo coal-fired generating station located at the southern end of Lake Powell was completed in 1976. Another power plant, the Kaiparowitz Project, was also proposed for construction near Lake Powell and became an issue of substantial public concern.

As part of the Lake Powell experiment, during the summer of 1974, interviewers attempted to determine the aggregate willingness of Lake Powell users to pay to prevent construction of the proposed Kaiparowitz plant (5). Interviewers showed photographs of the existing Navajo power plant with visible pollution emanating from the stacks and with the stacks alone. All of the interviewees had seen the actual stacks, which remain visible more than 20 miles up the lake. Interviewers then asked what entrance fee persons would willingly pay to prevent construction of another similar plant, first, where only pollution would be visible from the lake itself, and second, where both stacks and pollution would be visible.

The analysis of the data focused on strategic bias. If users believed a uniform entrance fee might be based on the average bid of the sample to prevent construction or if users believed construction plans might be affected by the research results, then "environmentalists" might well bid very high, and "developers" might well bid zero dollars in an attempt to bias the results. A theoretical model of strategic bias was constructed to explain the distribution of observed bids likely to be bimodal rather than normally distributed if strategic bias were present. The fact that the actual distribution of bids was normally distributed was taken as evidence that strategic bias was not present. It was suggested by Brookshire et al. (5) that the absence of strategic bias might be due to the hypothetical nature of the experiment--few respondents felt that their answers would affect real world outcomes. In sampling that was randomly conducted for the four principal users of Lake Powell, on the lake, in campgrounds, at motels, and in the town of Page, the highest refusal rate was less than 1 per cent.

The average bid per family or group was $2.77 in additional entrance fees in 1974 dollars. and the total annual bid--which can be interpreted as an aggregate marginal willingness to pay to prevent one additional power plant near Lake Powell--was over $700 000. The results show impressive consistencies with the one previous study (20) in the region as well as with the succeeding Farmington experiment.

Study 3: Visibility and Aesthetics at Farmington

This study reported in Blank et al. (23) and Rowe et al. (24) attempted to establish the economic value of visibility over long distances for Farmington residents and users of Navajo Reservoir. Clearly, the ability to observe long distances is almost a pure public good. Examined in this study was the extent of certain biases that the Brookshire et al. (5) study identified. These were information, strategic, starting point, and instrument biases on compensating and equivalent surplus measures of consumer surplus.

Visitors and residents in the Four Corners region of New Mexico and Arizona were interviewed. The interviewee was shown a set of pictures depicting visible ranges. Picture set C had a visible range of 25 miles, and picture sets B and A were 50 and 75 miles, respectively. The pictures represented views in different directions from the same location--the San Juan Mountains and Shiprock.

The first part of the experiment was a bidding game, structurally similar to that of Randall et al. (19, 20) and Brookshire et al. (5). A sequence of questions on maximum willingness to pay and minimum compensation was asked through a survey instrument. The second method followed that of Rosen (25), Muellbauer (26), and Hori (27) in attempting to use the household production function, in a methodological cross check by collecting market type information through a survey instrument. The contingent behavior component of the questionnaire attempted, through contingent changes in time allocation, to infer an expenditure function and compensated demand curve, primarily by postulating the exact form of a utility function and estimating a time-related household technology (23).

It is interesting to compare results of the Farmington study with previous studies. Randall et al. (19) only reported, and Brookshire et al. (5) only obtained equivalent surplus bids. The following comparisons presented in Table 2 are, therefore, limited to the equivalent surplus bids. Using the sales tax as the instrument, Randall et al. (19) reported yearly mean bids of $85.00 ($4.31) for moves from the highest level of environmental damage, situation (A), to situation (C) representing lowest levels of environmental damage; situation (B) represented an intermediate level of damage (28). A yearly mean bid of $50.00 ($3.02) per household was reported for moves from situation (B) to situation (C). The Farmington experiment yearly mean bids for the comparable situations were $82.20 ($9.10) and $57.00 ($4.63). If one considers that the Randall et al. (20) figures should be higher as respondents are also bidding on soil banks and transmission lines, these figures are comparable.

The overall mean for situation (A), good visibility, to (C), poor visibility, in the Lake Powell experiment (5), was $2.77 ($.19) per day. Adjusted for the 6.6 per cent inflation between the time periods of the studies, these values become $2.95 ($.20). The overall mean for users of recreational sites for the comparable situation in the Farmington experiment was $4.06 ($1.11), which is considerably different. However, the mean bid was $2.44 ($1.23) when $1.00 starting bids were used in the Farmington experiment, which corresponds to the Lake Powell starting bid. Thus, while still statistically different for the same starting bids, the results are much closer. The Farmington experiment, while not designed as a replication, demonstrated reasonable consistency with other studies. Finally, a comparison of values for similar sub-samples between the Four Corners and the Lake Powell experiments--respectively, of $1.79 ($.19) and $1.52 ($.29)--also suggest consistency.

Study 4: Visibility in the National Parklands

This study was designed to measure the economic value of preserving visibility in the national parklands of the Southwest. During the summer of 1980, over 600 people in Denver, Los Angeles, Albuquerque, and Chicago were shown sets of photographs depicting five levels of regional visibility (haze) in Mesa Verde, Zion, and Grand Canyon National Parks. Although calculations in the study suggest that projected emissions with existing and currently planned SO_2 controls would not produce a perceived decline in visibility, complete decontrol of SO_2 emissions by projected power plants in the region in 1990 would result in a decrease in typical summer visibility from what was represented in the photographs as "average" visibility to what was represented as "below average" visiblity.

On the basis of this, the survey participants were asked how much they would be willing to pay in higher electric utility bills to preserve the current average condition--middle picture--rather than allow visibility to deteriorate, on the average, to the next worse condition as represented in the photographs (an estimate of total preservation value). They were also asked about their willingness to pay in the form of higher monthly electric power bills to prevent visual plume in a pristine area. To represent plume blight, two photographs were taken from Grand Canyon National Park, one with a visible plume. The surveying has a very high response rate (few refusals).

Individual household bids ranged from an average of $3.72 per month in Denver to $9.00 per month in Chicago for preserving visibility at the Grand Canyon. This visibility degradation corresponds to an increase in fine particulate matter concentrations of .4 $\mu g/m^3$--a decrease in visual range from 240 km to 210 km. These average bids were increased by $2.89 to $7.10 per month per household in the four cities if visibility preservation were to be extended to the Grand Canyon region as a whole as represented by the photographs taken from Mesa Verde and Zion. Prevention of a visible plume at the Grand Canyon was worth on the average between $2.84 and $4.32 per month for interviewees in the four cities surveyed.

Extrapolating these bids to the nation implies that preserving visibility in the Grand Canyon region is worth almost 6 billion dollars per year. This is the base figure from which the benefits of power plant SO_2 controls, projected to be in place in the region in 1990, are determined. Adjusting this number for 1990 population levels and using a 10 per cent discount rate over a thirty-year power plant life gives an annualized value of 7.6 billion dollars as the benefit of power plant SO_2 control in 1990. These figures imply a marginal valuation on SO_2 of nearly $13 per pound of SO_2.

Reconciling the Costs and Benefits of Air Pollution Control

The costs of air pollution control and damage from air pollution were treated separately in the last two sections. The purpose of this section is to reconcile costs of control with damage to answer specific questions. What level of pollution control represents an appropriate balancing of costs and damages? Are current regulations consistent with such a level, or do current regulations over- or under-control pollution?

The first question concerns an optimal balancing of costs and damages. Let us focus on visibility protection, which, as we saw in previous sections, is one of the most important air quality values in the West. In terms of visibility, regional haze appears to be a more serious problem than plume blight, at least in control costs. As long as sources can be precluded from locating near Class I areas, plume blight should be a manageable problem. Regional haze control is potentially much more formidable because changing source location does not appear to be an effective control. Regional haze appears to be tied closely to aggregate emissions of SO_2 over a wide region (4, 29).

To control regional haze, suppose we place a cap on emissions of SO_2 in the Four Corners study region. We allow different sources to negotiate or trade rights among themselves so that the cap on emissions is achieved in a least cost manner. The economic model of air pollution regulation mentioned above can then be used to simulate industrial response and costs of such a lid on SO_2 emissions. In fact, the results of utilizing such a cap were presented in Fig. 5. There we showed the average (over the three demand scenarios) additional and marginal cost of SO_2 control as the lid on SO_2 emissions becomes tighter.

The optimal level of SO_2 emissions is that level where the marginal cost of emission control equals the marginal damage from a unit of emission. In the last section we saw that marginal visibility damage in the Grand Canyon region is approximately $13 per pound of SO_2. As can be inferred from Fig. 5, at an optimum this represents a very low level of SO_2 emissions, far lower than that implied by current regulations. Unquestionably there is a great deal of uncertainty in these damage estimates. However, even if they are an order of magnitude too high, they suggest that current regulations are not nearly strict enough to control regional haze in the study region.

Conclusions

The current system for regulating air pollution has a number of important features that relate to its efficiency in developing energy while preserving air quality. First, the Clean Air Act permits large development in the mountain West. Second, by requiring best available control technology, the act appears to be relatively effective at containing growth of SO_2, currently the pollutant with emissions most responsible for the visibility impacts in the region. Third, the act encourages siting away from Class I areas and thus diminishes the likelihood of visible plume impacts in national parks. Finally, the act appears to achieve these goals at costs commensurate with other regulatory alternatives as long as only energy sources are considered.

Our review of the willingness to pay to avoid visibility degradation in the Grand Canyon suggests that visibility is a highly valued resource in the west. Further, given the visibility protection provided by current regulations, SO_2 regulation is not overly strict. In fact, current regulations may undercontrol SO_2 in relation to visibility degradation.

However, the act does have some shortcomings that may prove increasingly important in the future. First, control of oxides of nitrogen is relatively indirect. Nitrates formed from oxides of nitrogen are apt to exhibit a threshold phenomenon with respect to visibility. At low concentrations and high temperature, nitrates are gases and consequently have negligible effects on visibility. At higher concentration with lower temperatures, small nitrate aerosols will form and influence visibility.

Similarly, in the instances where increments are met by efficient control of sulfur oxides, the visibility protection against plume blight may be inadequate. In these instances, the Federal land managers must demonstrate adverse effects, and budget pressures may prevent employment of sufficient resources to make such demonstrations.

While the act seems to be reasonably efficient at achieving air quality goals if sources with similar costs are considered, it may be less so if other sources are considered. Retrofit of SO_2 controls for smelters offers two options. First, it would be possible to achieve the same overall air quality at lower cost if smelters were controlled and lower controls were required of power plants. Second, significantly improved air quality in the parks could be achieved if smelters were controlled in addition to effective controls on power plants. The very large damage estimates associated with visibility impairment appear to imply that further control of SO_2 is warranted.

The act also has a major shortcoming in the regulation of fugitive dust. The construction of a new plant presently may result in non-attainment of ambient standards with negligible emissions. To date, fugitive dust has not played a major role in plant siting or control, but in the future such regulation could be a significant factor in plant siting decisions.

References and Notes

1. J. Trijonis, "Visibility in the Southwest--The Exploration of the Historical Data Base," Atmos. Environ. 13, 833-843 (1979).

2. D. Nochumson, "An Evaluation of Regional Haze Visibility Impacts," 8th Energy Techn. Conf. Exposition Proc., Washington, DC, March 9-11, 1981.

3. "Matrix Methods to Analyze Long-Range Transport of Air Pollutants," US Department of Energy, Assistant Secretary for Environment, Office of Environmental Assessments Regional Impacts Division report DOE/EV-0127 (January 1981).

4. D. Nochumson, "NCAQ Report 2: Air Quality in the Four Corners Study Region. Vol. II: Regional Analysis," Los Alamos National Laboratory LA-UR-81-1145, March 1981.

5. D. Brookshire, B. Ives, and W. Schulze, "The Valuation of Aesthetic Preferences," J. Environ. Econ. Manage. 3, 4, 325-346 (December 1976).

6. G. R. Neuroth, "Ambient Visibility and Particulates in Arizona During the 1980 Copper Smelter Strike," Arizona Department of Health Services, Bureau of Air Quality Control (December 31, 1981).

7. C. A. Mangeng and R. Mead, "Sulfur Dioxide Emissions from Primary Non-Ferrous Smelters in the Western United States," Los Alamos Scientific Laboratory report LA-8268-MS (August 1980).

8. P. A. Hamilton et al., The Reserve Base of U.S. Coals by Sulfur Content, Volume II: The Western States, Information Circular 8693 (Department of the Interior, Bureau of Mines, Washington, DC, 1975), p. 7.

9. Ambient standards are levels that define the allowable concentrations of pollutants at ground level.

10. H. E. Hesketh, "Economic Process Technology and Cost Curve Development Data and Procedures for Coal-Fired Electrical Generation Facilities," in "Air Pollution Control Costs and Regional Impacts in the Four Corners Study Region," F. Roach and J. Jaksch, Los Alamos National Laboratory LA-UR-81-1379, Los Alamos, New Mexico (March 1981).

11. Examples of such change are numerous and include the Huntington Canyon Power Plant and Intermountain Power Project, both in Utah.

12. Actual costs may be less because a move of 100 miles may not increase transport distances by 100 miles.

13. "Predicted Costs of Environmental Controls for a Commercial Oil Shale Industry," prepared by the Denver Research Institute for the US Department of Energy COO-5107-1 (July 1979).

14. The model is a static partial equilibrium model with the Four Corners region divided into 22 subregions. For more information, refer to Roach et al. (15).

15. F. Roach, J. Bartlit, A. Kneese, C. Kolstad, D. Nochumson, R. Tobin, G. Weatherford, and M. Williams, "NCAQ Report 4: Alternative Air Quality Policy Analysis for the Four Corners Study Region," Los Alamos National Laboratory, LA-UR-81-1380, March 1981.

16. Above and beyond those installed before 1987.

17. Unless otherwise indicated, costs are in 1980$ throughout this chapter.

18. L. B. Lave and E. P. Seskin, Air Pollution and Human Health (Johns Hopkins Press, Baltimore, 1977).

19. A. Randall, B. Ives, and C. Eastman, "Benefits of Abating Aesthetic Environmental Damage from the Four Corners Power Plant, Fruitland, New Mexico," New Mexico State University Agricultural Experiment Station, Bulletin 618 (1974).

20. A. Randall, B. Ives, and C. Eastman, "Bidding Games for Valuation of Aesthetic Environmental Improvements," J. Environ. Econ. Manage. 1, 2, 132-149 (August 1974).

21. R. Davis, "Recreation Planning as an Economic Problem," Nat. Resour. J. 3, 239-249 (May 1963).

22. P. Bohm, "Estimating Demand for Public Goods: An Experiment," Eur. Econ. Rev. 3, 2, 11-130 (1972).

23. F. Blank, D. Brookshire, T. Crocker, R. D'Arge, R. Horst, Jr., and R. Rowe, "Valuation of Aesthetic Preferences: A Case Study of the Economic Value of Visibility," Resource and Environmental Economics Laboratory, University of Wyoming report to the Electric Power Research Institute, 1977.

24. R. Rowe, R. D'Arge, and D. Brookshire, "An Experiment on the Economic Value of Visibility," J. Environ. Econ. Manage. 7, 1, 1-19 (March 1980).

25. S. Rosen, "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition," J. Pol. Econ. 82, 1, 34-55 (January/February 1974).

26. J. Muellbauer, "Household Production Theory, Quality, and the 'Hedonic Technique'," Amer. Econ. Rev. 64, 6, 977-994 (December 1974).

27. H. Hori, "Revealed Preferences for Public Goods," Amer. Econ. Rev. 65, 5, 978-991 (December 1975).

28. Standard errors are in parentheses.

29. M. D. Williams, C. A. Mangeng, S. Barr, and R. Lewis, "NCAQ Report 2: Air Quality in the Four Corners Study Region. Vol. I: Local Analysis," Los Alamos National Laboratory, LA-UR-81-1145, March 1981.

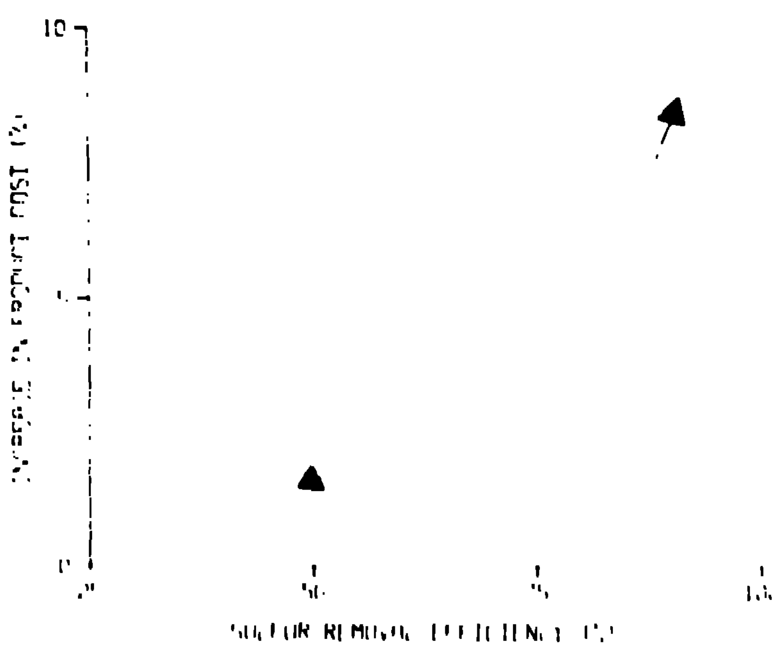
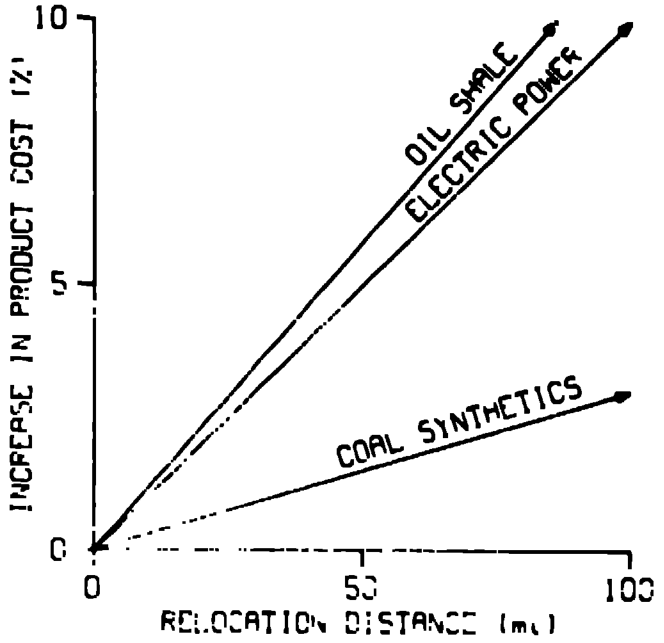


Figure 1. Electric power SO_2 control costs [based on \$.03/kWh cost from Hesketh (10)].



BASIS

1. COAL/SHALE SHIPMENT AT $.02/TON-mi
2. COAL AT 20 MILLION Btu/TON
3. ELECTRIC POWER

   TRANSMISSION AT .02 MILLS kWh/mi
   CONVERSION AT 9500 Btu/kWh
   PRODUCT AT $.03 kWh

4. COAL SYNTHETICS

   CONVERSION EFFICIENCY AT 60%
   PRODUCT AT $5.25/MILLION Btu

5. OIL SHALE

   FEED AT 25 gal. OIL/TON
   PRODUCT AT $30/bbl

Figure 2. Potential increase in costs from relocation.

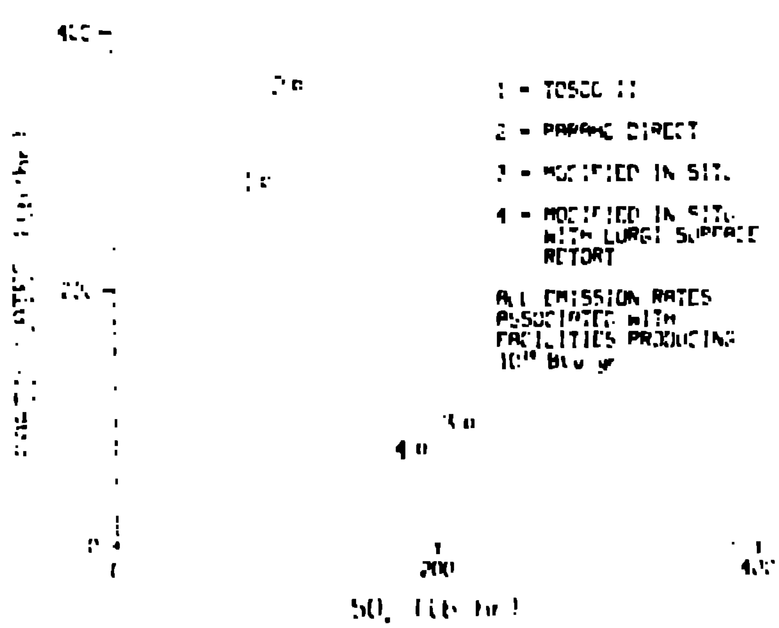
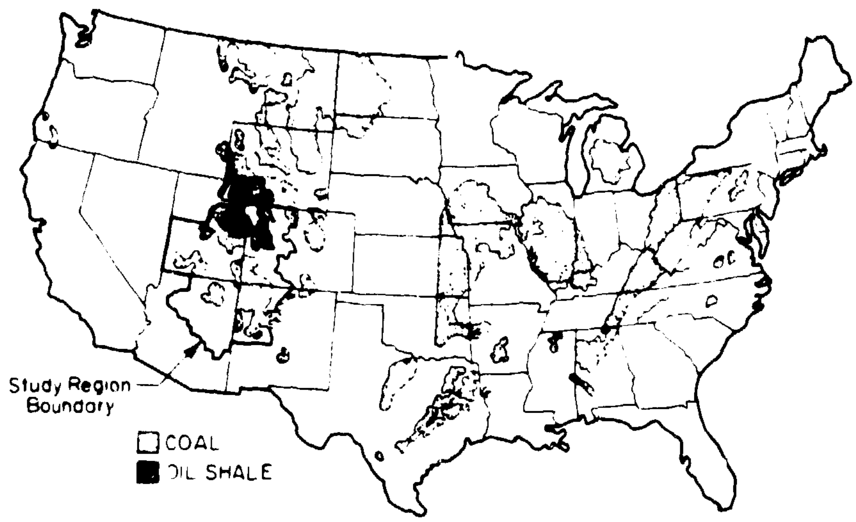
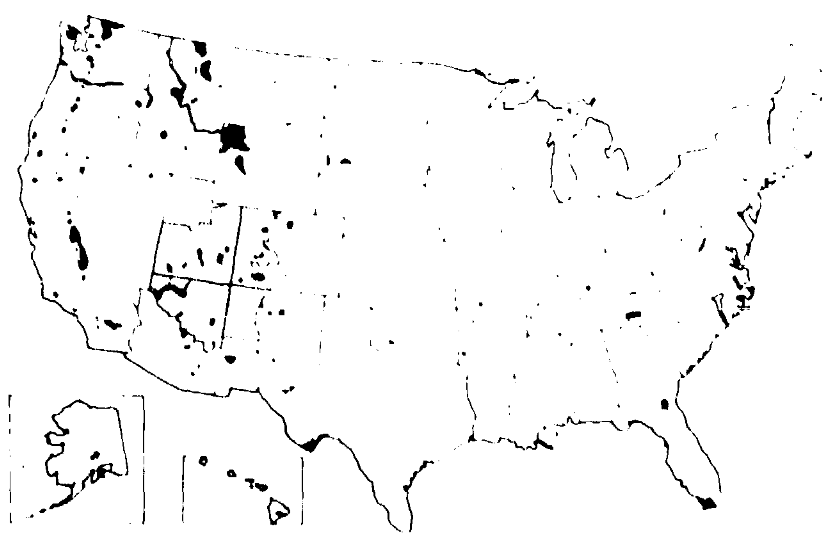


Figure 3. Oil shale, SO_2, and particulate emissions.



(a) Coal and principal oil-shale regions.



(b) Mandatory Class I areas.

Fig. 4. The Four Corners study region.

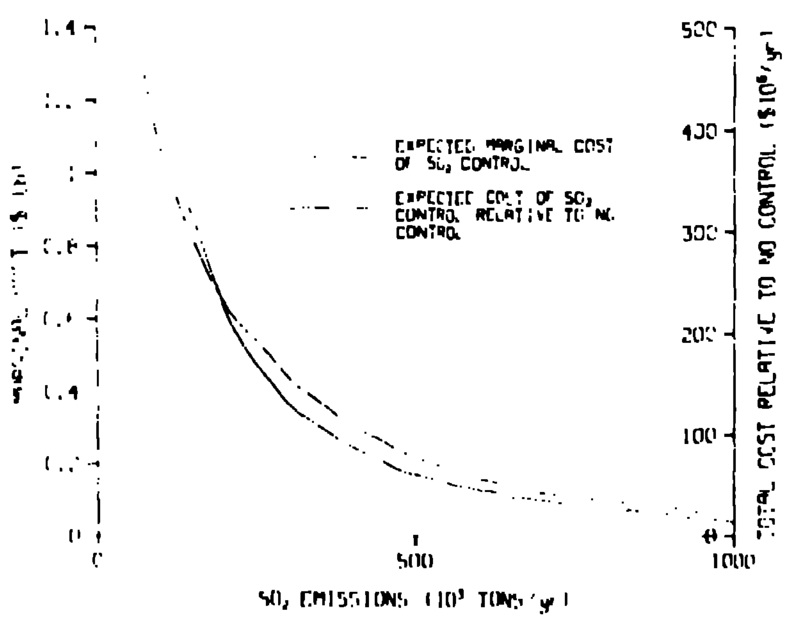


Figure 5. Costs of SO_2 control in study region.

Table 2. Comparison of results for southwest visibility studies[a]

Non-Market Valuation Studies	Public Good	Instrument	Comparisons			
			1[b]	2[b]	3[c]	4[c]
Four Corners experiment	Visibility, soil banks, transmission lines (aesthetics of the above)	Sales tax	\$85[d] (4.31)[g]	\$50 (3.02)	NA[e]	\$1.79[f] (0.19)
Lake Powell experiment	Visibility (aesthetics only)	Access fee	NA	NA	\$2.95[h] (2.0)	\$1.52 (0.29)
Farmington experiment	Visibility (aesthetics only)	Utility bills or wage tax	\$82 (9.10)	\$57 (4.63)	\$2.44[i] (0.23)	NA

[a]The Four Corners experiment (19, 20) and the Lake Powell experiment (5) only obtained equivalent surplus bids, thus comparisons between studies are limited to subsamples of the data sets from each study.

[b]Yearly mean bids.

[c]Bid per day.

[d]The comparison between the Four Corners experiment and the Farmington experiment (23, 24) is for two alternative levels of environmental quality changes.

[e]NA--No comparison can be constructed.

[f]The comparison between the Four Corners experiment and the Lake Powell experiment required different comparisons than did the Four Corners experiment with the Farmington experiment.

[g]Standard errors in ( ).

[h]Adjusted for 6.6% inflation.

[i]Mean bid for \$1.00 starting points in the Farmington experiment, which is the starting point used in the Lake Powell experiment.